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FINAL REPORT

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Bright photoelectron beams emitted from excimer-laser illuminated LaB_6

ABSTRACT

Lanthanum hexaboride has traditionally been used as a high-temperature thermionic emitter of electrons. This material, whose work function for a sintered multicrystalline composition is nominally 2.6 eV, appears to be a reasonably good photoemitter when irradiated by UV light. A quantum efficiency of 10^{-3} was recorded for photoemission at a 193 nm (ArF) incident wavelength. At least 20 A/cm^2 were observed at 193 nm, 248 nm (KrF) and 308 (XeCl). Beam brightness appears to be a minimum of 4×10^5 A/cm^2-rad^2 at 248 nm.

1. INTRODUCTION

Military and commercial needs exist for very bright electron sources to be used in a host of electronic devices ranging from free-electron lasers to advanced electron beam lithography equipment. Cathodes are required which will generate beams of electrons with high-current density and minimal electron energy spread. Photoemission can meet these demands, if the cathode is irradiated by a sufficiently strong laser at a wavelength near the radiative threshold of the photoemissive material. Conventional semiconductor photocathodes will emit under visible wavelength illumination, but are very susceptible to contamination, and must be operated in a very good ($\lesssim 10^{-9}$ torr) vacuum. As a result, a search is under way to find other materials that are more environmentally stable. Of special interest is lanthanum hexaboride (LaB_6), a thermionic material that photoemits electrons under UV irradiation.

A limited number of photoemissive studies of LaB_6 have been performed. Some of the earliest results were reported by Lafferty in 1951[1]. In experiments conducted at vacuum pressure levels below 10^{-7} torr in a sealed-off device, he measured the spectral distribution of photoemitted electrons over an energy range of approximately 3.4 eV photons, from 2.8 eV to 6.2 eV. Considering this distribution to be dominantly that of a metal, Lafferty deduced the work function of LaB_6 from his data, by Fowler's method, to be 2.67 eV. He noted that this value was in excellent agreement with the 2.66 eV measured thermionically, a result indicating that the work function was not appreciably temperature-dependent. The quantum efficiencies determined from Lafferty's curve at the three excimer wavelengths of interest in our present study, 193 nm (ArF), 248 nm (KrF), and 308 nm (XeCl), were, respectively, $6.3(10^{-4})$, $5(10^{-4})$, and $2(10^{-4})$.

Photoemission from single crystal <110> LaB_6 was also measured recently by Mogren and Reifenberger[2]. In order to fit theoretical curves to their data they concluded that, in contrast to Lafferty's result, the work function probably does depend on temperature. A value of 2.58 ± 0.1 eV was determined, in good agreement with the 2.67 eV established by Lafferty.

If LaB_6 can be characterized as a metal with no band gap, and with a work function of roughly 2.6 eV, then its photoemissive threshold will be at a visible wavelength of approximately 475 nm, substantially above the 275 nm or so associated with conventional metals such as copper or aluminum[3]. Moreover, if the quantum efficiencies of this material in the UV, as quoted by Lafferty, are correct, its photoemissive yield will be one to two orders above that of the traditional metals. Then, irradiating LaB_6 with a visible laser emitting near the photoemissive threshold could generate a very bright beam of electrons.

The normalized brightness B_n, of an electron beam is defined as[4]

$$B_n = \frac{I}{\pi^2 \varepsilon_n^2} \tag{1}$$

where I is the beam current and ε_n its normalized emittance

$$\varepsilon_n = \gamma \beta r \frac{p_\perp}{p_\parallel} \tag{2}$$

γ is the relativistic mass factor, β, is the ratio of the beam's axial velocity to c, the speed of light, r is the beam radius, and $p_\perp / p_\parallel$ is the ratio of the electron perpendicular-to-axial momenta. In terms of the electron's perpendicular energy, $E_\perp$, and its rest mass, m_o, equ (2) can be rewritten as

$$\varepsilon_n \simeq r \left(\frac{2\ E_\perp}{m_o\ c^2} \right)^{1/2} \tag{3}$$

The objectives of this study were to determine I and ε_n of electron beams generated from unpolarized excimer-laser-irradiated multicrystalline LaB_6 surfaces, and, thereby, provide estimates of B_n.

2. EXPERIMENT

Photoemission from sintered, multicrystalline LaB_6 is being studied in two experimental arrangements. A normal incidence configuration, shown in Figure 1, was first used to measure emission from a 0.5 cm^2 sample irradiated by an unpolarized excimer laser operating at one of three UV wavelengths, 193 nm (ArF) 248 nm (KrF), or 308 nm (XeCl). Subsequently, beam brightness was, and is continuing to be, measured in a more complex geometry (Figure 2) wherein the excimer laser beam is incident at a large angle onto a 0.95 cm^2 sample.

In the first arrangement, the laser beam passes through a tungsten grid anode positioned 4 to 7 mm from the cathode. 1 kV electron beam heating, to a minimum of 1800 K for several minutes, bakes out - and removes lanthanum oxide from the surface - of the LaB_6. It also also allows measurement of the thermionic emission, and, thus, the work function of the material, whose surface temperature was determined with an optical pyrometer. When desired, a heated silver tube allows a controlled amount of oxygen to enter the vacuum chamber, normally kept at pressures below 10^{-7} torr. A Pearson probe measures the generated pulsed photocurrents which are recorded as oscillograms on a dual-beam 400 MHz oscilloscope. The oscilloscope was triggered from the laser power supply with sufficient delay to allow good resolution (20 ns/division) traces to be recorded. The laser pulse is simultaneously recorded by deflecting, with a wire, a small fraction of the laser beam to a photodiode. Laser output was measured with a Scientech power energy meter. The radiation falling on the LaB_6 surface was calculated taking into consideration the transmission of the chamber quartz window (50% at 193 nm, 80% at 248 nm, 95% at 308 nm).

To determine beam brightness (Figure 2) the laser beam is shaped into a square by two quartz cylindrical lenses and focussed onto a 0.95 cm^2 LaB_6 surface. After thermally cleaning the surface with the electron beam, the LaB_6 is irradiated by 20-ns (FWHM) pulses from the laser incident at an angle of approximately 70 degrees to its surface.

The photoemissive electrons transverse a 9-mm-long interelectrode region to an elongated anode. Voltages up to 55 kV were applied to this electrode. At the entrance of the anode, the electrons encountered a 1-mil thin tungsten foil pepperpot containing five 1-mil-diameter holes patterned in a cross of four holes, each of which was located 3 mm from the axial hole. Electrons passing through these holes then transversed a 14-cm-long, field-free region before impacting on a P-1 phosphor screen. Images of the resultant spots on the screen were photographically recorded through another window in the vacuum chamber.

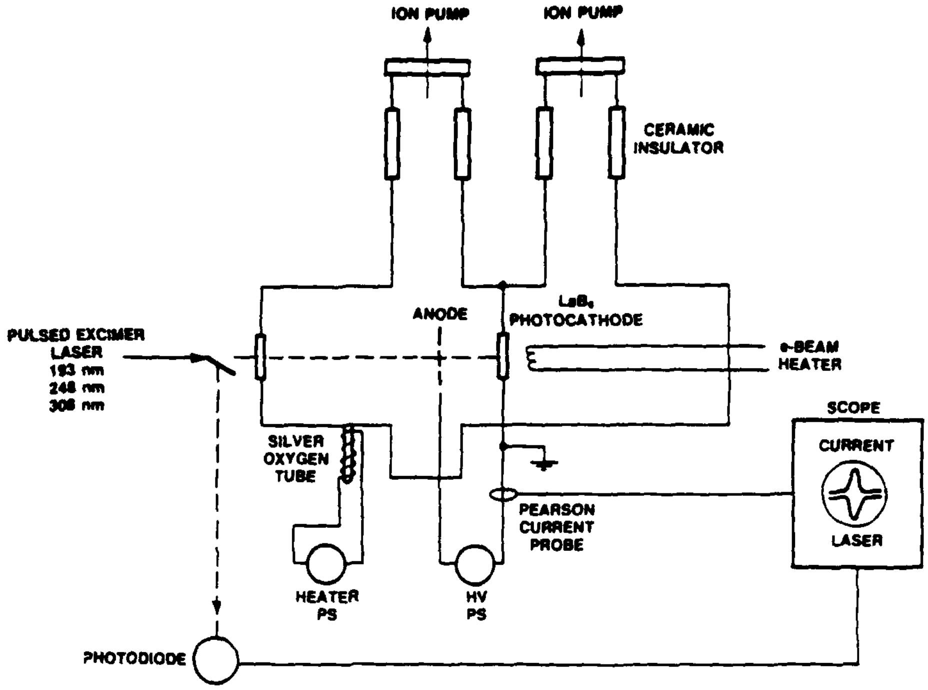

Figure 1. Experimental Arrangement with Excimer Laser Beam at Normal Incidence Onto LaB_6 Surface

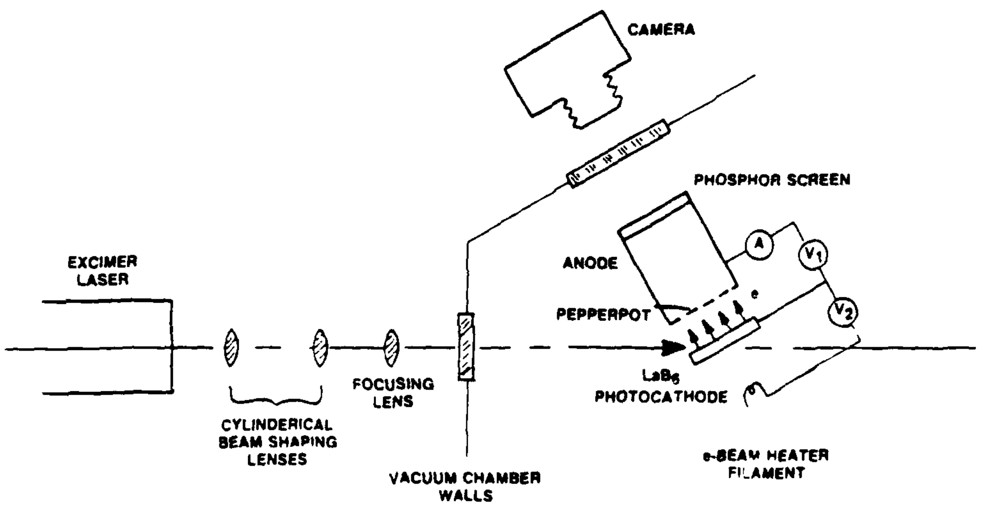

Figure 2. Experimental Arrangement to Measure Beam Brightness of Electrons Photoemitted by LaB_6

3. DISCUSSION

The flow of photoelectrons from the LaB_6 cathode to the pepperpot anode, and the subsequent fractional flow of these electrons across the field-free drift region to the phosphor screen, is schematically depicted in Figure 3.

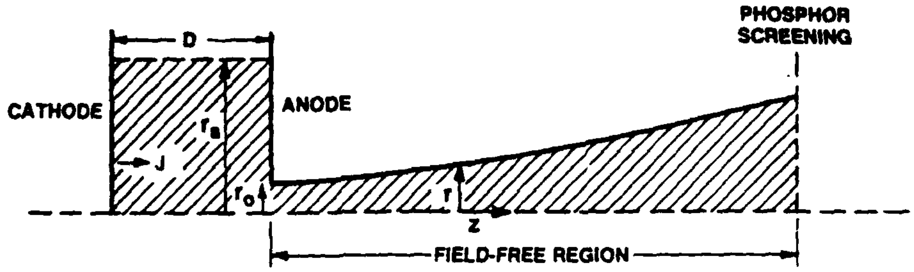

Figure 3. Flowfield of Electrons in the Experimental Arrangement Shown in Figure 2

Expansion of the beamlets in the drift region is caused by optical defocussing of the electrons passing through the pepperpot holes, space charge effects in traversing the anode, and beam emittance caused by the transverse energy of the photoelectrons emitted from the cathode. The shape of the electron beam under the influence of these effects is governed by the envelope equation[5],

$$\frac{d^2r}{dz^2} - \frac{K}{r} - \frac{\varepsilon_b^2}{r^3} = 0 \tag{4}$$

For a weakly relativistic beam,

$$K = \frac{e\, J_o\, r_o^2}{2\, \epsilon_o\, m_o\, (\gamma\beta c)^3} \tag{5}$$

where J_o is the beam current density at the pepperpot and r_o is the radius of the pepperpot holes. The emittance of the beamlet ε_b is related to the normalized beam emittance by

$$\varepsilon_b = \frac{\varepsilon_n}{\gamma\beta}\frac{r_o}{r_a} \tag{6}$$

where r_a is the full beam's radius in the diode at the pepperpot.

A boundary condition on eq. 4 was the optical defocussing of the beamlets at the pepperpot holes ($z = 0$),

$$\left(\frac{dr}{dz}\right)_{z=0} = \frac{r_o}{nD} \tag{7}$$

where the diode spacing is denoted by D, and n is equated to a value between 3 and 4 depending on the strength of the space charge. Numerically integrating the envelope equation for the diode geometry, applied voltage, and measured current provided a relation between transverse energy spread [i.e., beam emittance from eq. 3] and spot diameter on the phosphor screen. By matching the measured spot size to this calculated value, the normalized beam emittance was established. Note that this emittance, often called the rms emittance was determined by considering only a few points in the beam. It is, therefore, only an estimate, which for a reasonably uniform beam is a good approximation of this parameter.

By electron beam heating the LaB_6 in situ and measuring the thermionically emitted current, the surface work function could be measured. In this manner, a value of 2.53 eV was determined for a thermally cleaned sample emitting at 1325 K. This number is seen to be consistent with those determined by Lafferty and by Mogren and Reifenberger.

A series of experiments is ongoing to establish the maximum current densities, quantum efficiencies, and beam brightnesses of the UV laser irradiated multicrystalline LaB_6. The data obtained so far indicate that over 20 A/cm^2 can be generated at the three pertinent wavelengths. A quantum efficiency, measured for an ArF laser output of 6.2 mJ, was approximately 10^{-3}, somewhat larger than recorded by Lafferty[1] (Figure 4).

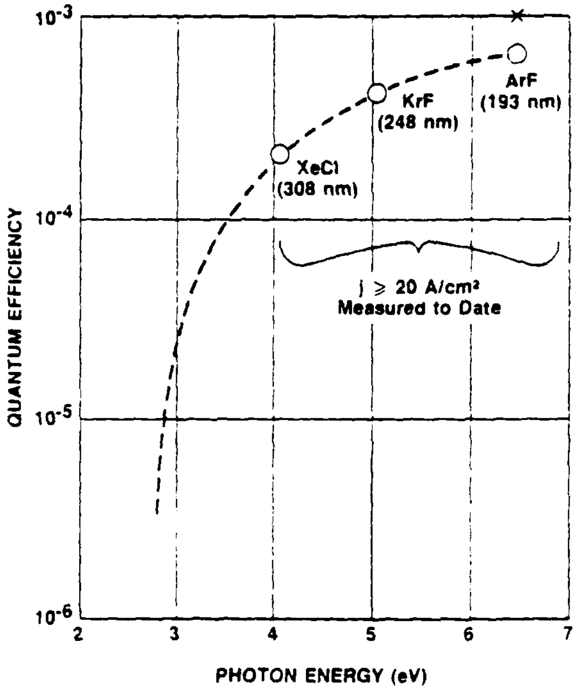

Figure 4. Quantum Efficiency of LaB_6 at 300 K [Dashed curves taken from J.M. Lafferty, J. Appl. Phys. 22, 299 (1951). Points shown correspond to laser wavelengths of the present study, preliminary measurement for ArF given by x.]

A pattern of spots on the phosphor screen for 248 nm irradiation of LaB_6 is shown in Figure 5. Because one of the five pepperpot holes was occluded, only four spots are visible. For a relatively low current of 6 A/cm^2, the normalized brightness deduced from this pattern is approximately 4×10^5 A/cm^2-rad^2. Full sets of data covering the three excimer wavelengths, are being compiled.

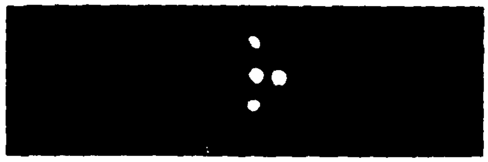

Figure 5. Pattern of Four Spots on the P-1 Phosphor Screen when the LaB_6 was Irradiated at 248 nm. Spot diameter ~1.45 mm. (Note: One of the five holes was occluded).

Although the photoemissive tests were generally performed in a vacuum of 10^{-7} torr, raising this level an order of magnitude to 10^{-6} torr, by introducing pure oxygen through the silver tube, did not change the emitted current.

4. CONCLUSIONS

The data presently available, although incomplete, indicates that LaB_6 can photoemit substantial quantities of electrons when irradiated by UV excimer lasers. The quantum efficiency associated with this emission is at least an order of magnitude above that of pure metals, but several orders below that of conventional semiconductor photocathodes. Beam brightness appears to be quite large, although not quite as high as the 10^7 A/cm^2-rad^2 measured for Cs_3Sb photocathodes[6,7].

The experiments have been performed so far at reasonably good vacuums of better than 10^{-7} torr. A preliminary result which indicates that some oxygen introduction to 10^{-6} torr does not degrade performance needs to be extended to 10^{-5} torr, in order to cover the range of typical accelerator vacuums. Moreover, the effects of other impurities (H_2O, hydrocarbons) needs to be examined.

When the incident radiation is linearly polarized and not normal to the LaB_6 surface, the orientation of the electric field to the surface may have a significant bearing on the photoemission. This effect has not yet been explored. The results of this study show, so far, that LaB_6 appears to be a significant photoemitter, responding to excimer wavelengths of up to at least 308 nm. If future tests prove that this material will operate satisfactorily in accelerator environments with a brightness somewhat larger than measured so far, then it may become a desirable high brightness electron source that could be driven, for example, by a frequency-tripled or quadrupled Nd:YAG laser.

5. ACKNOWLEDGMENTS

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Brightness measurements of electron beams photoemitted from multicrystalline LaB_6 and the effects of environmental pressure

ABSTRACT

Lanthanum hexaboride has been tested as a photoemitter when irradiated by unpolarized UV lasers. For photon energies of 5 eV or less, the material, in a multicrystalline form, is measured to have a quantum efficiency at least an order of magnitude greater than that of simple metals. Maximum currents, from a 1.27 cm^2 sample, limited by the available laser power, were recorded to be 52, 36, and 0.9 A at irradiating wavelengths of 193, 248, and 308 nm, respectively. At 193 and 248 nm the corresponding normalized rms brightnesses were 6.7×10^6 and 2.6×10^6 A/cm^2-rad^2. The results appear insensitive to chamber pressure in, at least, the range of 10^{-5} to 10^{-8} torr.

1. INTRODUCTION

The need for increasingly bright sources of electrons has grown during the last few years. Primarily required for more efficient, shorter wavelength (near infrared and optical) free electron lasers, such sources are also in demand by the particle physics community for the next generation of electron accelerators. Traditional sources, such as plasma-forming field emitters are restricted in brightness by the high temperature of the electrons. Moreover, the closure of the plasma front curtails the use of this kind of emitter. Another class of commonly used sources, thermionic cathodes, do provide relatively cold electrons, but the low emitted current densities significantly limit the brightness. Thus, there has been an increasing interest in an alternative type of cathode, namely, laser-driven photoemitters, which can generate very bright pulsed beams of electrons. Conventional semiconducting photocathodes, such as Cs_3Sb when irradiated by frequency-doubled Nd:glass- or Nd:YAG-lasers form beams with a normalized brightness of up to $10^7 A/cm^2$-rad^2[1,2]. Such cathodes are presently under development for free electron lasers [3], and are being considered for new particle accelerators at BNL and CERN. Other laser-driven photocathode materials, e.g., GaAs[4] and K_2CsSb[5], have also been researched. Although able to generate high current densities and very bright beams these photoemissive materials are thermally fragile and contaminant sensitive. Therefore, some consideration has been given to simple metal photoemitters because of their environmentally rugged surfaces. Unfortunately, emission from these metals is highly inefficient, with an extremely low yield of electrons per incident photon (quantum efficiency). As a result, a search is underway to identify new, resistant photoemissive materials whose quantum efficiencies may be lower than that of the conventional semiconductors (Q.E. ~ 10^{-2} - 10^{-1}), yet higher than that of metals (Q.E. ~ 10^{-6}). Recently, preliminary tests have been performed on LaB_6, a substance recognized for its thermionic, but not its photoemissive, properties. When a sintered multicrystalline sample of this compound was irradiated by an excimer laser emitting at 193 nm, a quantum efficiency near 10^{-3} was recorded with current densities (limited by the laser's power output) of over 20 A/cm^2[6]. A lower limit on the electron beam brightness, at a 248 nm excimer wavelength, was estimated to be 4×10^5 A/cm^2-rad^2. These results were sufficiently interesting to warrant further exploration of this material. Moreover, because LaB_6 operates thermionically at pressures of only 10^{-7} torr (two orders of magnitude greater pressures than tolerated by conventional semiconductor photocathodes), this compound might be expected to be a substantially more environmentally rugged photosurface as well. Thus, the present experiments are designed to determine the photoemissive brightness of electron beams generated from multicrystalline LaB_6 and to measure the effect of varying the vacuum level.

2. EXPERIMENT

The experimental arrangement (Figure 1) is similar to that shown in Figure 2 of reference 6. The excimer laser beam is focussed onto a 1.27 cm^2 sintered LaB_6 sample using two quartz cylindrical lenses. Experiments were performed with unpolarized laser beams at three UV wavelengths, 193 nm (ArF), 248 nm (KrF), and 308 nm (XeCl). The test chamber was pumped initially to a vacuum of 1.5 to 3×10^{-8} torr. Pulsed photocurrents were measured with a Pearson current monitor, whose sensitivity was 0.1V/A when terminated in 1 MΩ, and recorded on a dual-beam 400 MHz oscilloscope. The oscilloscope was triggered from the laser beam with sufficient delay to allow good resolution (10 ns/division)of the traces. Simultaneous measurements of the laser pulse was accomplished by deflecting, with a wire, a small fraction of the laser beam to a photodiode. Laser output was determined with a Scientech 362 power energy meter. The radiation falling on the LaB_6 surface was calculated taking into consideration the transmission of the chamber quartz window (50% at 193 nm, 80% at 248 nm, 95% at 308 nm).

The LaB_6 can be electron-beam heated up to a maximum of 1700 K in order to remove oxide contaminants from its surface, and to allow its surface work function to be determined thermionically. Because some of these surface-beam-heating electrons find their way to the anode, and thereby affect the thermionic measurements, a full wave rectified ac voltage was used to provide a 1500 V pulsed dc accelerating potential, modulated at 120 Hz, to the heating electrons. Thus, small dc thermionic currents could be readily distinguished from the ac background.

The LaB_6 was irradiated by 12 to 28 ns (FWHM) pulses (depending on the type of laser gas fill) from the laser beam incident onto the surface at an angle of approximately 70 degrees to the normal. The emitted photoelectrons entered an elongated anode through five 1-mil-diameter holes, configured into a cross, in a 1-mil thin annealed molybdenum foil pepperpot. They then traversed a 14-cm-long, field-free region to a P-1 phosphor screen overcoated with a thin aluminum film. Images of the resultant spots on the screen were photographically recorded through another window in the vacuum chamber.

Voltages up to 35 kV were applied to the diode by a Hipotronics power supply through 50 Ω cable. With a 5 MΩ charging resistor inserted at the HV feedthrough mounted to the anode, and a laser pulse rate of 2 to 5 Hz, an independent check on the peak currents recorded with the Pearson probe could be made by measuring the average voltage drop across this resistor.

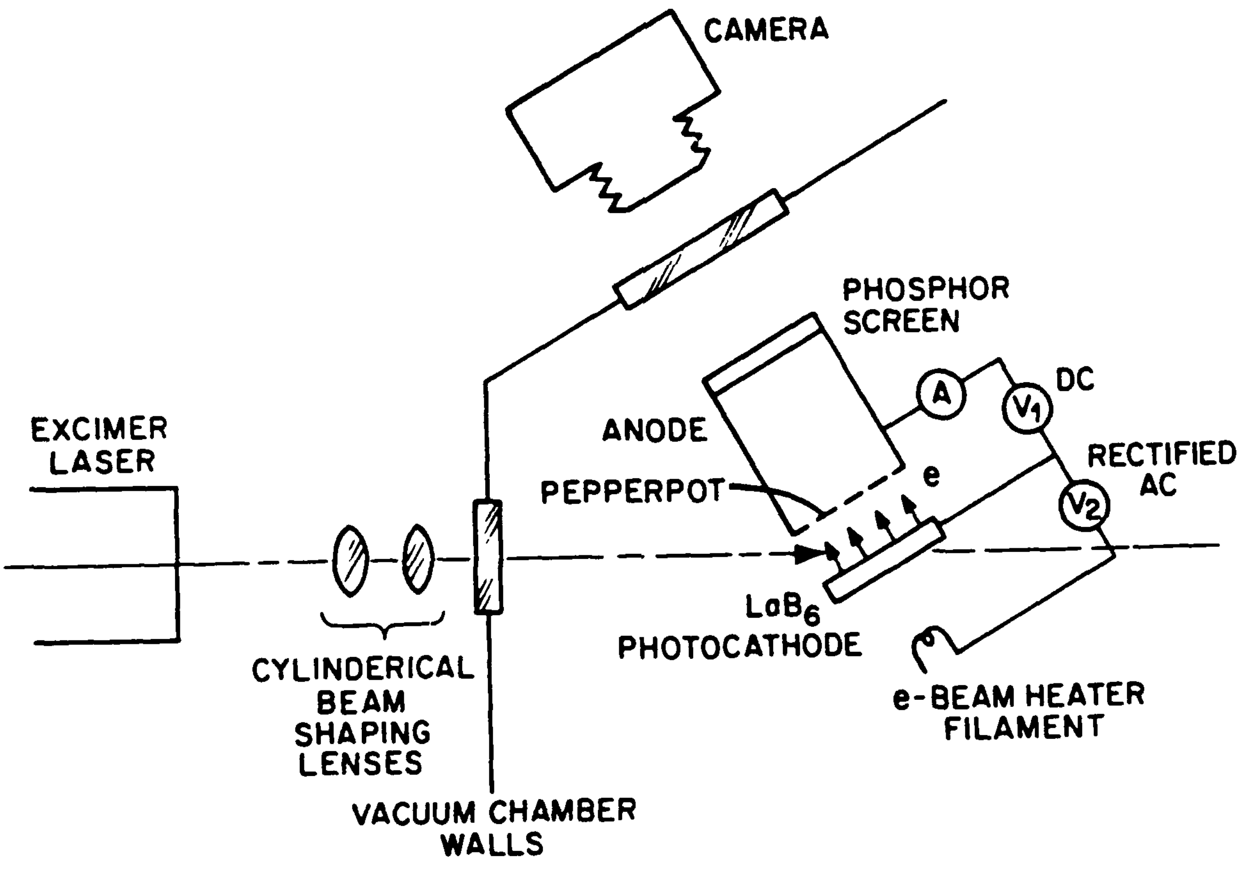

Figure 1. Experimental Arrangement to Measure Beam Brightness of Electrons Emitted by LaB_6

3. DISCUSSION

From the Pearson monitor, peak photocurrents of 52, 36, and 0.9A were recorded from LaB_6 irradiated with laser input powers onto the sample of 0.7, 4.5, and 2.9 MW, at, respectively, 193, 248, and 308 nm wavelengths. The corresponding quantum efficiencies are, 4.6×10^{-4} at 193 nm, 4.0×10^{-5} at 248 nm, and 1.3×10^{-6} at 308 nm. These measurements were made for the LaB_6 sample positioned in an ion pumped chamber evacuated to a pressure of 1.5 to 3×10^{-8} torr. Increasing the pressure three orders of magnitude to 10^{-5} torr by turning off the pump did not significantly affect the emitted current or beam brightness during KrF laser irradiation. Similar pressure variations did not seem to affect photocurrents generated from XeCl illuminated LaB_6. No such tests were performed for ArF. The quantum efficiencies of LaB_6 at the three laser wavelengths are plotted in Figure 2, as is a comparison curve taken from the work of Lafferty[7] The spread of data from several tests is depicted by the bars. Note that the values of the present experiments for ArF irradiation are lower than reported in our previous publication[6], possibly because the work function of the present sample at 2.9 eV is larger than the former sample's 2.53 eV. As seen in Figure 2, the curve is below that of Lafferty, whose LaB_6 sample's work function was 2.67 eV.

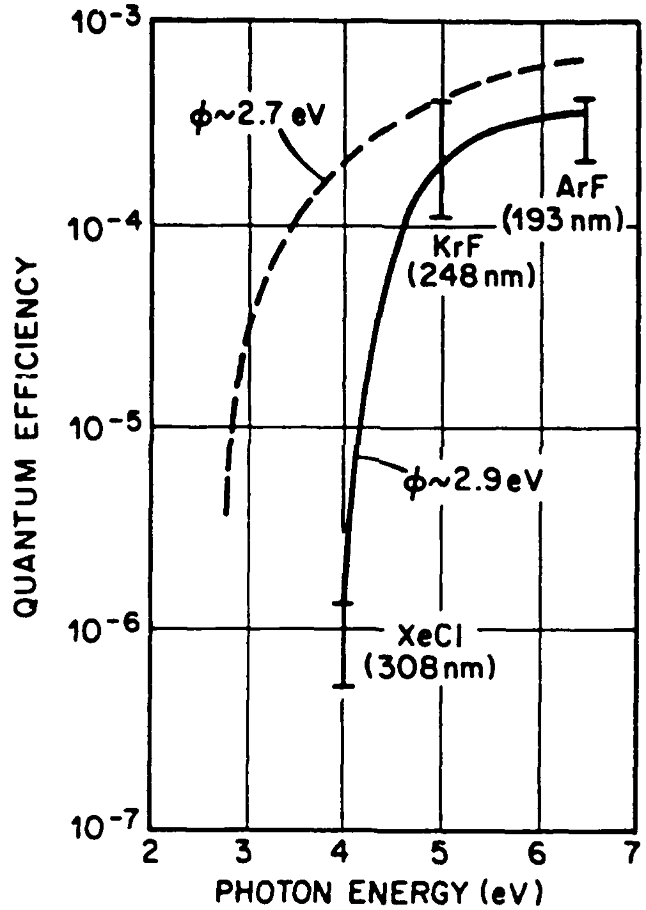

Figure 2. Quantum Efficiency of Multicrystalline LaB_6 with Work Function of 2.9 eV [Dashed curve taken from J.M. Lafferty, J. Appl. Phys. 22, 299 (1951)].

Beam brightness was determined by comparing the spot size diameters measured on the photographic images of the P-1 phosphor screen with theoretically derived values. The latter are based on the analytical model, described in Reference 6 wherein the beam envelope equation [8],

$$\frac{d^2 r}{dz^2} - \frac{K}{r} - \frac{\epsilon_b^2}{r^3} = 0 \tag{1}$$

is numerically solved for the beamlet image size, r at the phosphor screen subject to the optical defocussing boundary condition at the pepperpot holes

$$\left(\frac{dr}{dz} \right)_{z=0} = \frac{r_o}{nD} \tag{2}$$

Beam space charge and emittance effects are accounted for, in equation (1), by the second and third terms, respectively. An appropriate solution of this equation, which matches the calculated beamlet image size, to that measured, determines the correct emittance, ϵ_b, of the beamlet in the field-free anode drift space. This parameter can be related to the normalized rms emittance, ϵ_n, of the total beam in the diode, which in turn provides a value for the normalized beam brightness

$$B_n = \frac{I}{\Pi^2 \epsilon_n^2} \tag{3}$$

4. CONCLUSIONS

Measurements of photoemission from multicrystalline LaB_6 with a work function of 2.9 eV, irradiated by unpolarized UV laser beams has shown this compound to be a satisfactory photocathode with quantum efficiencies, at photon energies 5 eV or lower, over an order of magnitude greater than that of simple metals. Normalized rms beam brightness (see Figure 3) ranges, at a 193 nm wavelength, up to 6.7×10^6 A/cm^2-rad^2, comparable to that measured for Cs_3Sb irradiated at 532 nm[1]. At 248 nm it was 2.6×10^6 A/cm^2-rad^2, or one-half that observed for Cs_3Sb. The currents were too low at 308 nm for the formation of visible images of spots on the phosphor. The photoemission does not appear to degrade for KrF and XeCl illumination (ArF was not tested for this effect) as the environmental pressure (air) is raised up to at least 10^{-5} torr. The dependence of such photoemission on specific impurities, such as water vapor and hydrocarbons has not yet been determined. The latter species are especially important because of the organic materials used in many conventional accelerators. Nevertheless, the results of these experiments indicate that LaB_6 can provide very bright electron beams, and probably could, for example, be irradiated by a frequency quadrupled Nd:YAG laser to generate the trains of short electron bunches needed in free electron lasers.

5. ACKNOWLEDGEMENTS

The author is appreciative of the help provided by Mr. Jim Dodge who constructed the experimental apparatus and performed the tests. This research was supported by SDIO under Contract No. N00014-86-C-0598.

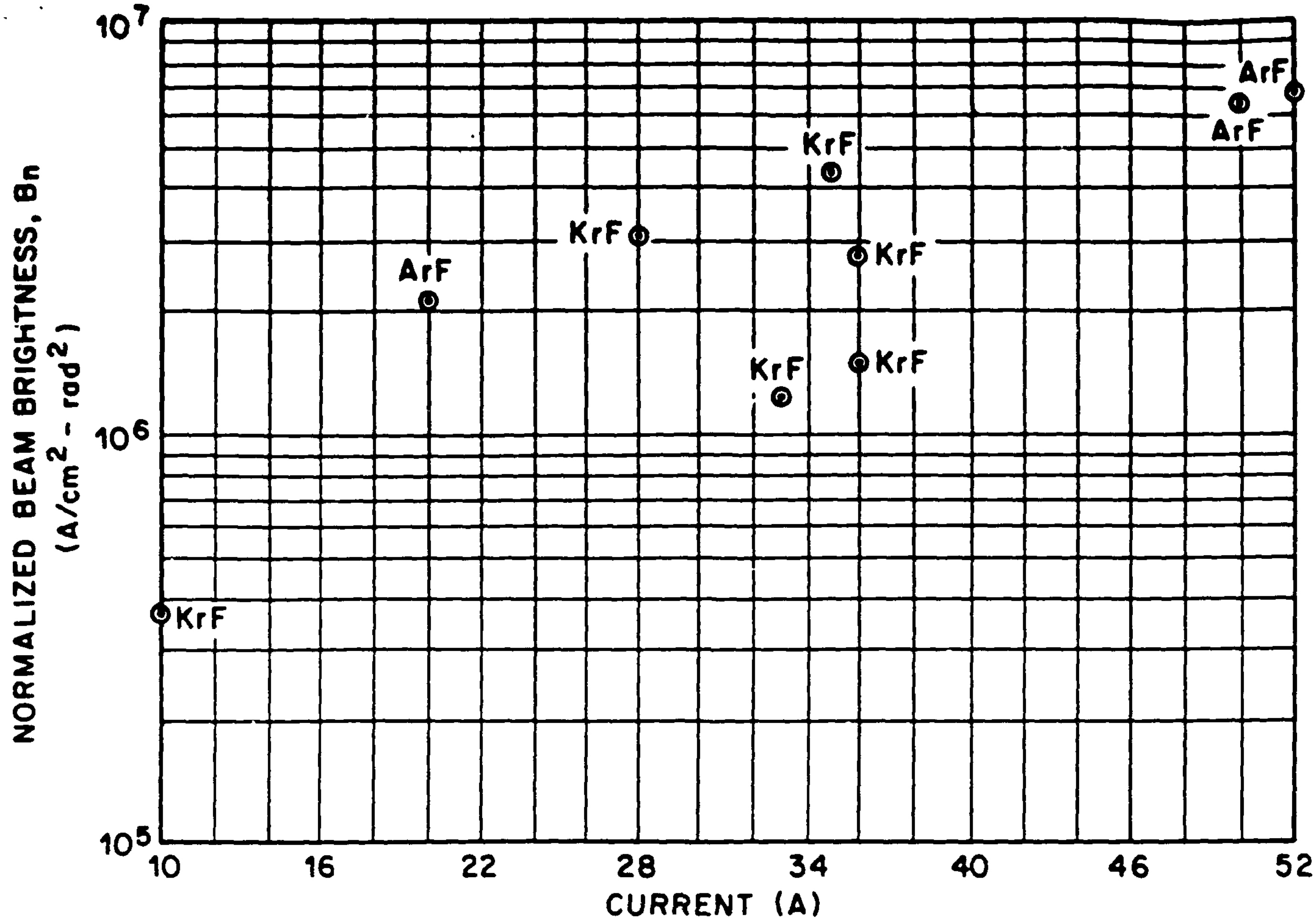

Figure 3. Normalized Beam Brightness as a Function of Current of Photoelectrons Emitted from a 1.27 cm^2 LaB_6 Surface Irradiated by 193 nm or 248 nm Photons.

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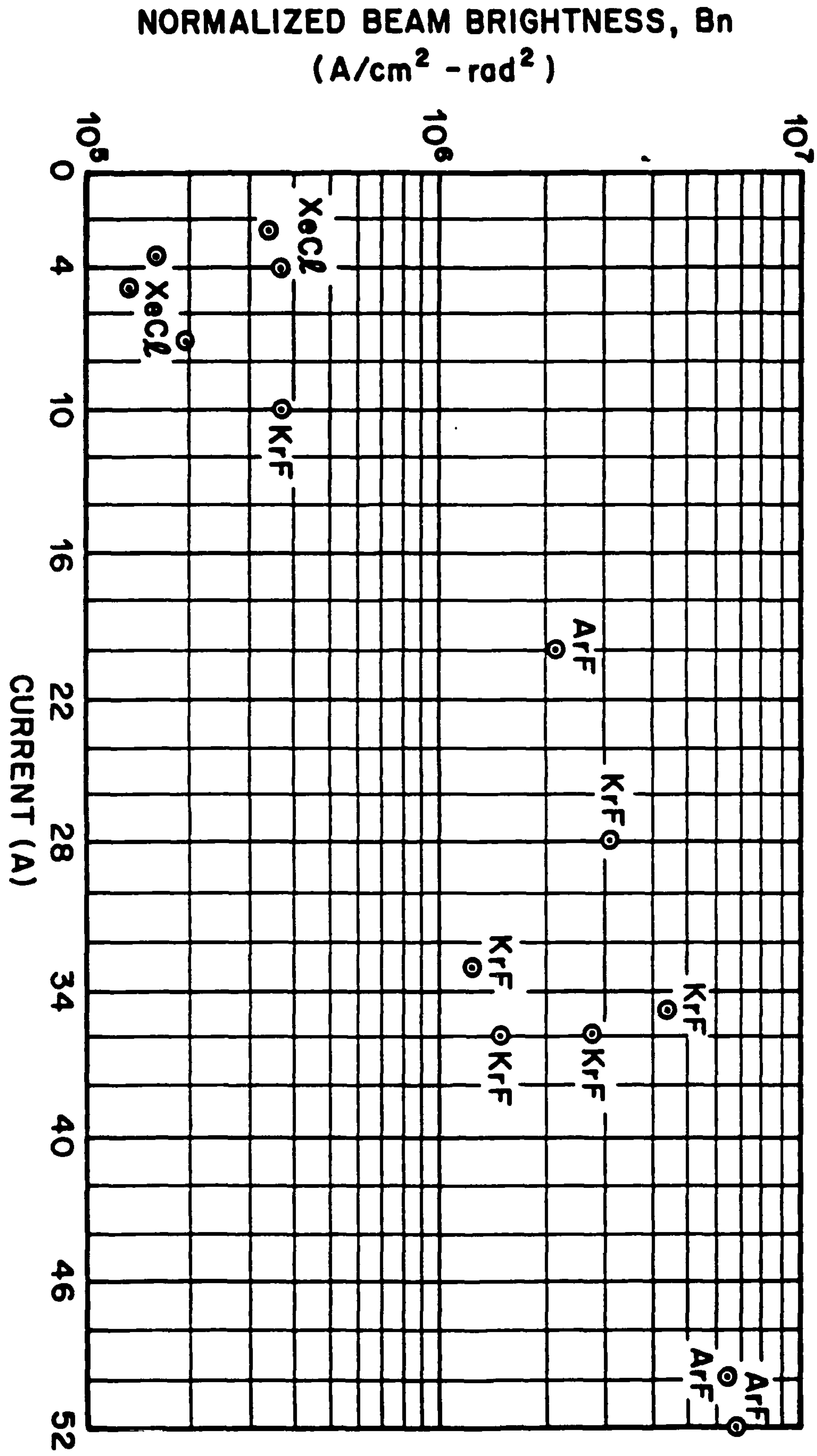
NORMALIZED BEAM BRIGHTNESS, Bn
(A/cm^2 -rad^2)
10^5
10^6
10^7
CURRENT (A)
0
4
10
16
22
28
34
40
46
52
XeCℓ
XeCℓ
KrF
ArF
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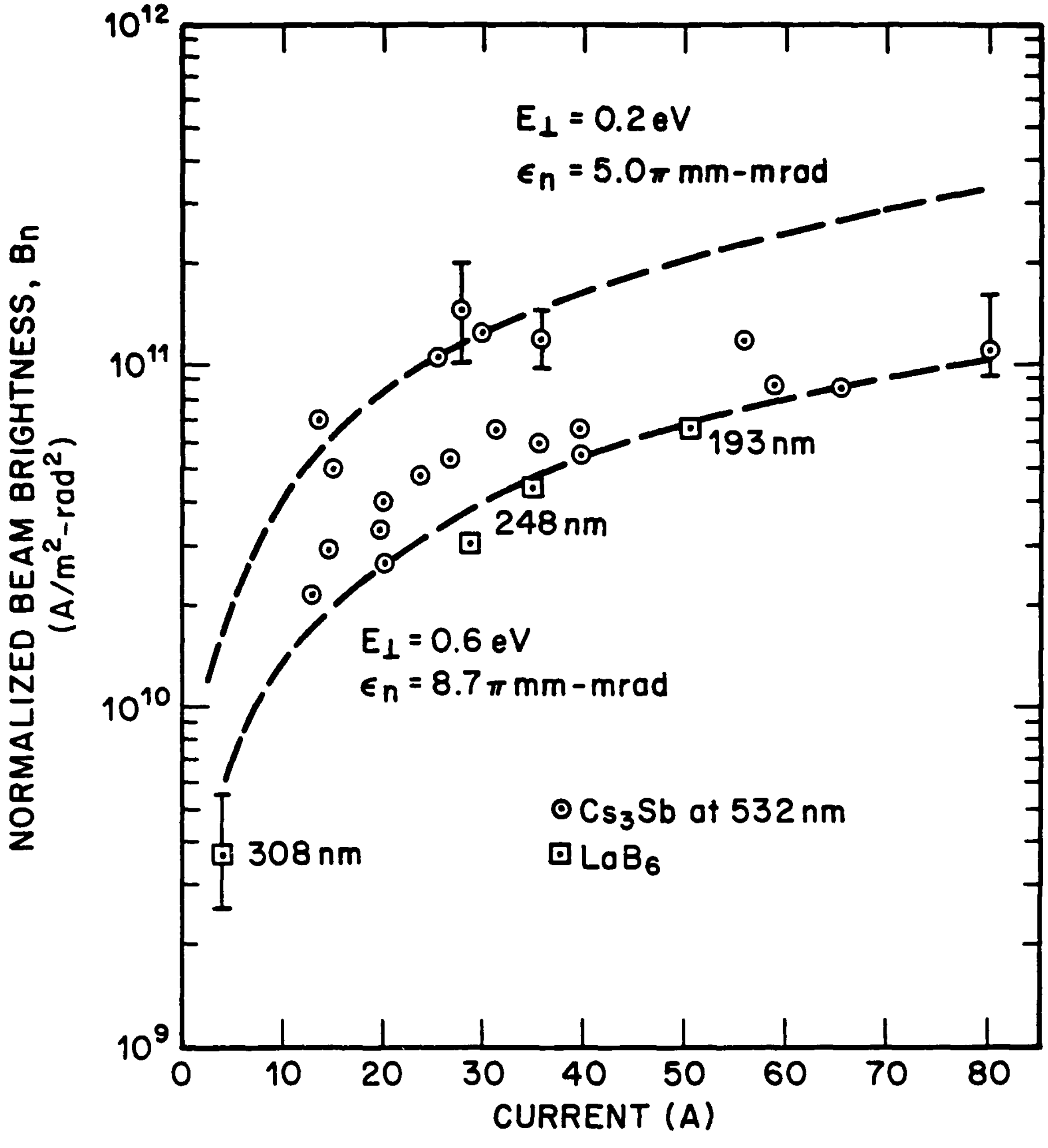
KrF
ArF
ArF



NORMALIZED BEAM BRIGHTNESS, Bn
(A/m²-rad²)
CURRENT (A)
E⊥ = 0.2 eV
εn = 5.0π mm-mrad
E⊥ = 0.6 eV
εn = 8.7π mm-mrad
193 nm
248 nm
308 nm
Cs3Sb at 532 nm
LaB6

Measured Brightness of Electron Beams Photoemitted from Multicrystalline LaB_6

ABSTRACT

Laser-driven semiconductor photoemitters can provide the very bright beams of electrons needed in advanced accelerators. However, these semiconductors are easily degraded in operation. Photoemissive testing of the compound LaB_6, which is expected to be a more environmentally rugged material, has shown that under excimer-laser irradiation normalized electron beam brightnesses of 6.7×10^6, 2.6×10^6, and 1.5×10^5 A/cm^2-rad^2 can be achieved at photon wavelengths, respectively, of 193, 248, and 308 nm.

Although, laser irradiation of conventional semiconducting photoemitters, such as cesium antimonide (Cs_3Sb), can provide high electron current densities and very bright beams,[1] these materials are thermally fragile and contaminant sensitive. This letter presents experimental data on the normalized brightness achievable in beams photoemitted from a more environmentally rugged substance, when its surface is irradiated by uv-excimer-laser pulses.

LaB_6 is a metallic-like substance recognized for its thermionic properties. In a series of early tests reported by Lafferty in 1951,[2] the spectral distribution of photoemitted electrons was measured over an energy range extending from 2.8 to 6.2 eV. Considering this distribution to be dominantly that of a metal, Lafferty determined from the data the work function, by Fowler's method, to be 2.67 eV, in excellent agreement with the 2.66 eV measured thermionically. At the 193 nm(ArF), 248 nm(KrF), and 308 nm(XeCl) excimer laser wavelengths of interest in the present study, the quantum efficiencies provided by Lafferty's data, were $6.3X10^{-4}$, $5X10^{-4}$, and $2X10^{-4}$, respectively. These measurements suggest that the photoemissive yields of LaB_6 will be at least one order of magnitude greater than that of traditional metals, such as copper and aluminum.[3]

To confirm these quantum efficiencies and measure the beam brightness, tests were performed in a $3X10^{-8}$ torr chamber using the experimental arrangement shown in Fig.1. An unpolarized laser beam emitting at either 193 nm, 248 nm, or 308 nm irradiated a 1.27 cm^2 sintered LaB_6 sample. Electron-beam heating the sample to 1700 K removed surface oxide contaminants and allowed the material's work function to be determined thermionically. Because some of these beam-heating electrons find their way to the anode, and thereby, affect the thermionic measurements, a rectified 120 Hz ac voltage accelerated the electrons, allowing them to be distinguished from the smaller dc thermionic currents. With the sample at room temperature, and using a Pearson current monitor, photocurrents were measured during excimer-laser uv-pulse irradiation of the sample. In these tests the laser pulse widths varied between 12 and 28 ns (FWHM), depending on the type of laser gas fill, and the laser beam was incident to the surface at an angle of approximately 70 degrees to the normal.

Using an elongated anode with a five-hole pepperpot entrance foil, the normalized emittance, ϵ_n, of the electron beam was determined in a similar manner to that described in Reference 1.

$$\epsilon_n \simeq r_c \left(2E_\perp / m_o c^2\right)^{1/2} \qquad (1)$$

r_c is the beam radius at the cathode, and $E_\perp$ is the average electron transverse energy at this electrode's surface, and can be considered to be a measure of the transverse energy spread of the beam. The normalized emittance, together with the measured photocurrents, established the normalized brightness, B_n, of the electron beam.

$$B_n = I/\pi^2 \epsilon_n^{\ 2} \qquad (2)$$

From the photocurrents and measured laser power the quantum efficiencies of LaB_6 at 193 nm, 248 nm, and 308 nm were calculated, the results of which are shown in Fig. 2. The thermionic work function of the sample in this study was approximately 2.9 eV. In comparison to the results of Lafferty, the quantum efficiencies are seen to be lower and the work function is larger. The bars on the graph depict the spread of data from several tests, and is attributed to a combination of changing surface properties and measurement inaccuracies.

The measured electron beam normalized rms brightnesses are presented in Fig. 3. They range from 6.7×10^6 A/cm^2-rad^2 at 193 nm down to 1.5×10^5 A/cm^2-rad^2 at 308 nm. Shown on this same figure for comparison are the data, reported in Ref. 1, for Cs_3Sb irradiated with a frequency-doubled Nd:YAG laser. The brightness of the electron beams generated from the LaB_6 at the excimer laser wavelengths are seen to be large, but somewhat below what had been measured for Cs_3Sb at 532 nm. This result is expected from the greater emittances of beams photoemitted from LaB_6, for which the energy difference between the irradiating wavelength and the material work function is larger than its corresponding quantity for Cs_3Sb.

Several measurements obtained for LaB_6 irradiated at 248 nm and at 308 nm with the chamber pressure (air) raised to 10^{-5} torr showed no significant change in the photoemitted current, indicating that the material is less susceptible to air contamination than is Cs_3Sb. The dependence of such photoemission on specific impurities, such as water vapor and hydrocarbons has not yet been determined. The latter species are of interest because of the organic materials used in many conventional accelerators.

The results of these experiments indicate that LaB_6 appears to photoemit in poorer vacuums than does Cs_3Sb, and can, apparently, provide very bright electron beams. The LaB_6 could, for example, be irradiated by a frequency-quadrupled Nd:YAG laser to generate the trains of short electron buncnes needed in free electron lasers.

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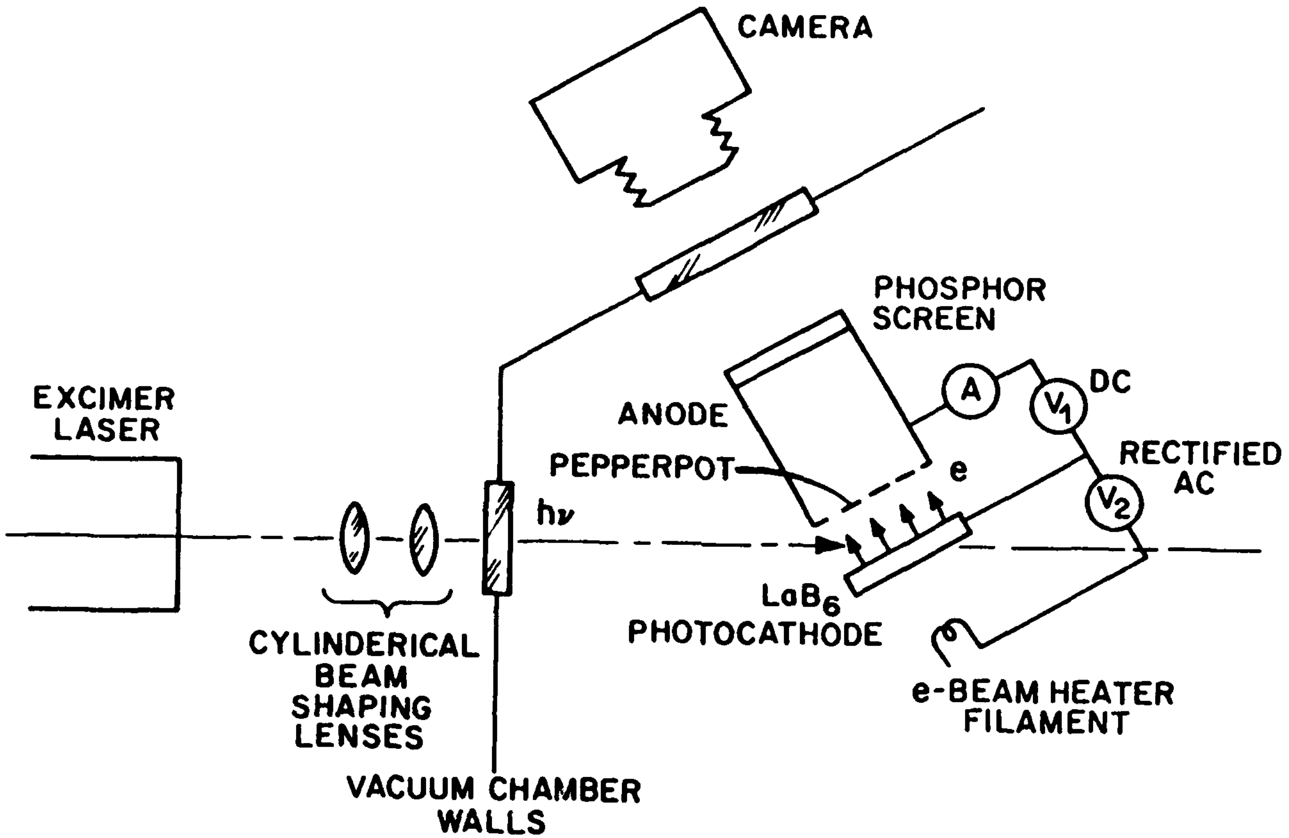
FIGURES

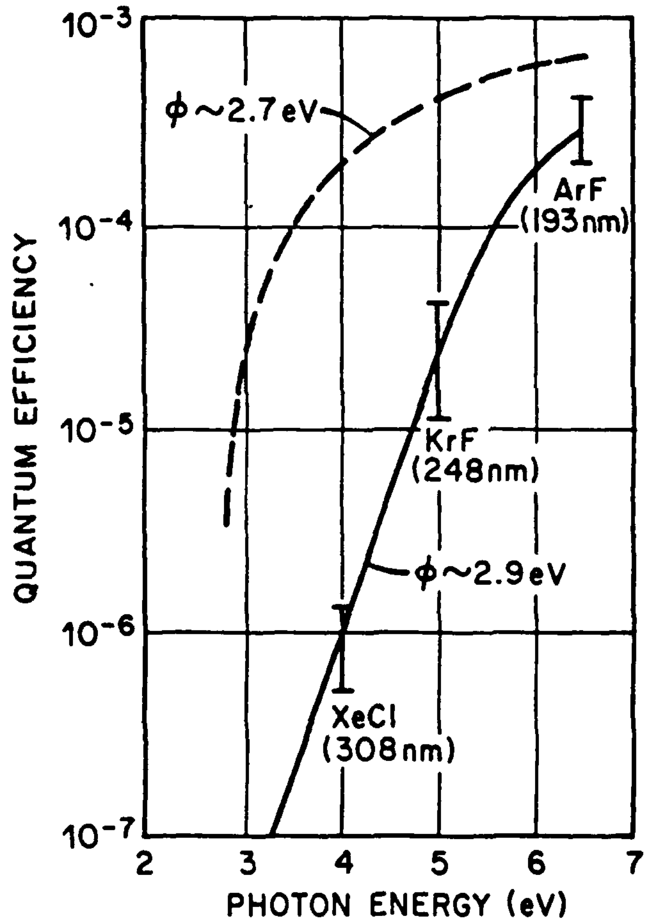
Figure 1. Experimental Apparatus Used to Measure the Photoemitted Beam Brightness from LaB_6.

Figure 2. Quantum Efficiency of Multicrystalline LaB_6 with Work Function of 2.9 eV (Dashed curve taken from J.M. Lafferty, J. Appl. Phys. 22,299 (1951)).

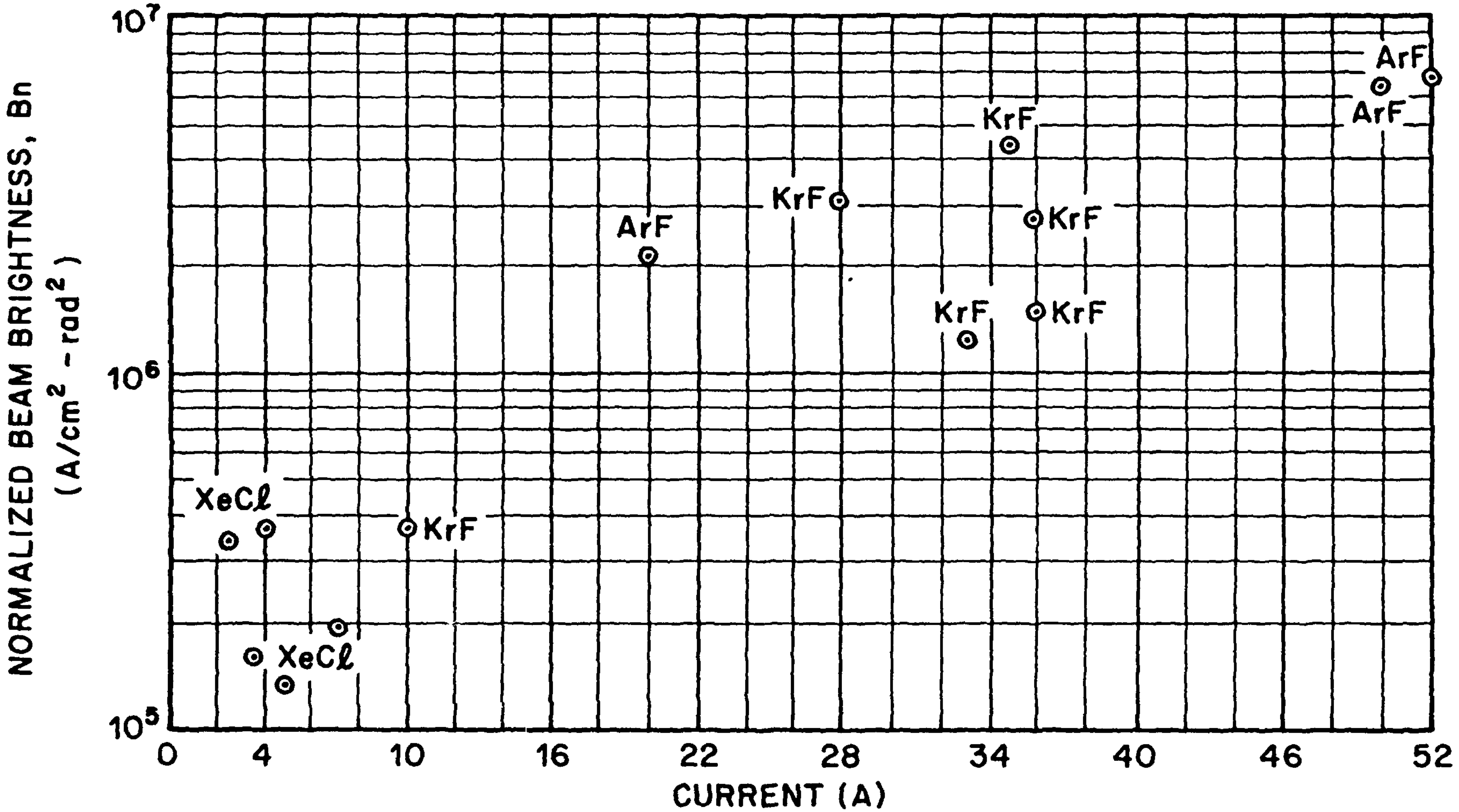
Figure 3. Normalized Beam Brightness as a Function of Photocurrent Emitted from a 1.27 cm^2 LaB_6 Sample Irradiated by 193 nm (ArF), 248 nm (KrF) and 308 nm (XeCl) Photons.



CAMERA
PHOSPHOR SCREEN
EXCIMER LASER
ANODE
A
V_1
DC
PEPPERPOT
e
RECTIFIED AC
V_2
$h\nu$
LaB_6 PHOTOCATHODE
CYLINDERICAL BEAM SHAPING LENSES
e-BEAM HEATER FILAMENT
VACUUM CHAMBER WALLS



QUANTUM EFFICIENCY
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
2
3
4
5
6
7
PHOTON ENERGY (eV)
$\phi \sim 2.7$ eV
$\phi \sim 2.9$ eV
ArF
(193nm)
KrF
(248nm)
XeCl
(308nm)



NORMALIZED BEAM BRIGHTNESS, Bn
(A/cm² - rad²)
10⁷
10⁶
10⁵
0
4
10
16
22
28
34
40
46
52
CURRENT (A)
XeCℓ
XeCℓ
KrF
ArF
KrF
KrF
KrF
KrF
KrF
ArF
ArF